AD-A169 901 THERMOPHYSICAL PROPERTIES MEASUREMENTS OF GALLIUM ARSENIDE AND CADMIUM TELLURIDE(U) GEOSCIENCE LTD SOLANA BEACH CALIF H F POPPENDIEK ET AL. JUN 86 GLR-254 1/1

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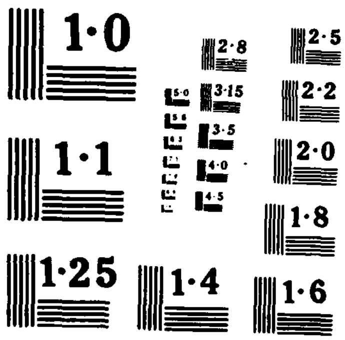
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARO 22600.1-MS-A	2. GOVT ACCESSION NO. N/A	3. RECIPIENT'S CATALOG NUMBER N/A
4. TITLE (and Subtitle) Thermophysical Properties Measurements of Gallium Arsenide and Cadmium Telluride		5. TYPE OF REPORT & PERIOD COVERED 1 Nov 84 - 31 Aug 86 Final Report
		6. PERFORMING ORG. REPORT NUMBER
AUTHOR(s) H. F. Poppendiek, C. M. Sabin, D. J. Connelly, P.M. Peuron, R.J. Whaley		8. CONTRACT OR GRANT NUMBER(s) DAAG29-85-C-0003
PERFORMING ORGANIZATION NAME AND ADDRESS Geoscience Ltd, 410 South Cedros Avenue, Solana Beach, CA 92075		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office, Post Office Box 12211, Research Triangle Park, NC 27709		12. REPORT DATE June 1986
		13. NUMBER OF PAGES 17
MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Same as above		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

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18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

GaAs and CdTe thermal conductivity, thermal coefficient of expansion, specific heat, emissivity, heat of fusion.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This final report summarizes the thermophysical properties measurements made for GaAs and CdTe. Specifically, grey body emissivities and thermal coefficients of expansion were determined.

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GLR-254

FINAL REPORT
THERMOPHYSICAL PROPERTIES MEASUREMENTS OF GALLIUM ARSENIDE AND CADMIUM TELLURIDE

For The

U. S. Army Research Office

Contract No. DAAG29-85-C-0003

By

H. F. Poppendiek
C. M. Sabin
D. J. Connelly
P. M. Peuron
R. J. Whaley

June 1986

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Solana Beach, California 92075

I. STATEMENT OF PROBLEM STUDIED

Geoscience is under contract to the U. S. Army to measure thermophysical properties of two semiconductor materials, cadmium telluride and gallium arsenide. The specific properties to be determined are

- coefficient of linear thermal expansion,
- specific heat,
- grey body emissivity, and
- thermal conductivity.

Some specific heat and thermal conductivity measurements on cadmium telluride were previously made by Geoscience. It had not been possible to completely characterize the test materials supplied for these investigations.

During this study, Geoscience developed a new method of making infrared emissivity measurements at higher temperatures with no particular limitations*. This final report summarizes the results of emissivity and coefficient of thermal expansion measurements made for both cadmium telluride and gallium arsenide.

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II. CHARACTERIZATION OF THE SAMPLES TESTED

Geoscience utilized new samples with specific geometries for the measurement work performed. According to the supplier,* the samples have the following characteristics.

gallium arsenide:

grown resistivity	$> 10^8$ ohm-cm
electron mobility	$\sim$ 5000 cm^2/Vs

cadmium telluride:

grown resistivity	10^6 to 10^8 ohm-cm
impurity content	$< 10^{17}$ cm^{-3}
dislocation density	10^5 to 10^6 cm^{-2}

---

*The CdTe and GaAs test samples were supplied and characterized by Westinghouse Electric Corporation.

III. THE NEW EMISSIVITY MEASUREMENT SYSTEM

The new measurement system consisting of a microslug surrounded by high temperature thermal insulation is fit into a high reflectivity collimation tube. A fine gauge thermocouple whose junction is located at the center of the microslug calorimeter is connected to a high speed recording potentiometer as shown. This system is then a microslug radiation calorimeter.

A test sample, heated by a metallic foil through which an electric current is being passed, is positioned horizontally as shown in Figure 1. After the sample has come up to thermal equilibrium, the radiation calorimeter system is quickly positioned under the test sample. The angle factor of the collimation tube of the radiation calorimeter is such that the sensing slug only sees the test sample surface. As soon as the radiation from the sample falls on the microslug radiation sensor, its temperature rises linearly as is shown in Figure 2. A heat balance on the microslug radiation calorimeter is defined by the following equation:

$$\alpha_s G A_s = m_s c_{p_s} \frac{dt_s}{d\theta} + C_\ell (t_s - t_o) A_t \tag{1}$$

where

α_s , the infrared absorptivity of the microslug surface

G , the infrared specimen radiation falling on the microslug surface

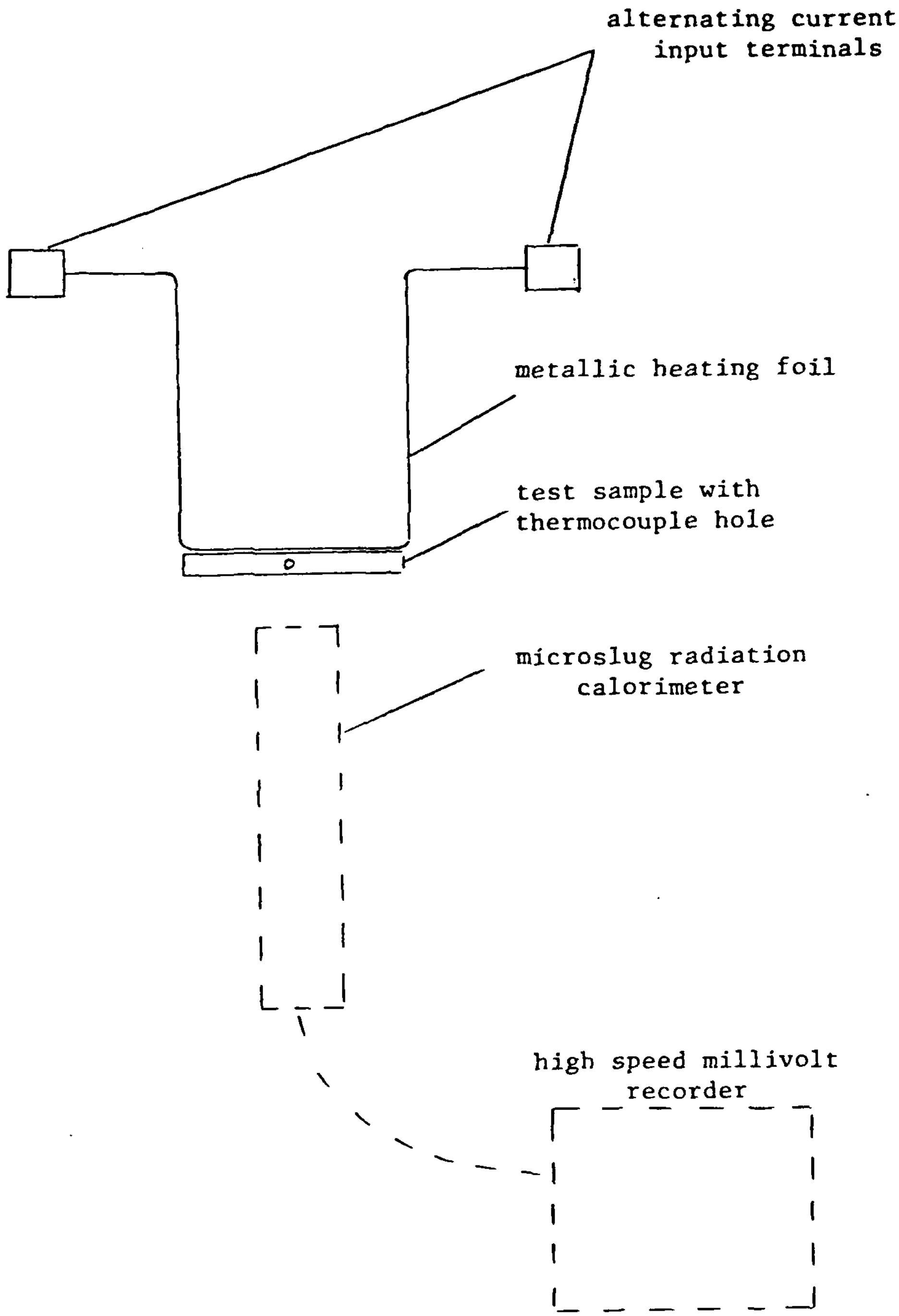


Figure 1. Test sample heating system.

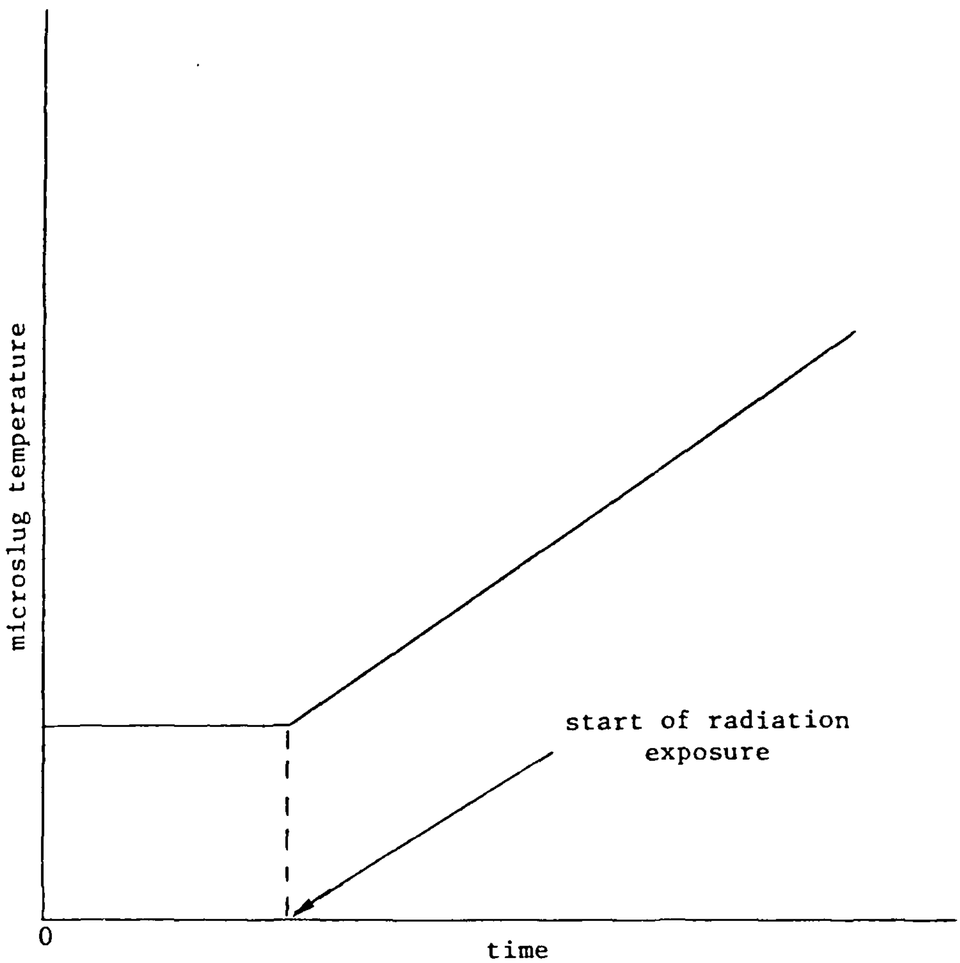


Figure 2. A schematic representation of a recorder trace of a microslug temperature rise after exposure to thermal radiation.

A_s , the receiving area of the microslug

m_s , the mass of the microslug

c_{p_s} , the specific heat of the microslug

t_s , the microslug temperature

θ , the time

C_ℓ , the combined convection and conduction heat loss conductance for the microslug

t_o , the initial temperature datum of the microslug radiometer

A_t , total surface area of microslug

The radiation falling on the microslug surface can be expressed as

$$G = \varepsilon F \sigma T^4 \qquad (2)$$

where

ε , the test sample infrared emissivity

F , the geometrical shape factor for the radiation system

σ , Stephen Boltzman constant

T , the absolute surface temperature of the test sample

Equations (1) and (2) can be rearranged so that the infrared emissivity of the test sample can be determined as follows:

$$\varepsilon = \frac{m_s \, c_{p_s} \frac{dt_s}{d\theta} + C_\ell \, (t_s - t_c) \, A_t}{\alpha_s \, A_s \, F \, \sigma \, T^4} \tag{3}$$

It can be shown that for short radiation exposure times, the second term in the numerator of Equation 3, namely, the heat loss term is small and negligible in comparison to the heat absorption term.

It is also possible to express the emissivity of a test sample in terms of absorbed radiation ratios for a test sample and a standard material whose emissivity is known. For example, if the microslug radiometer measures the radiation coming from a test sample at a known, fixed temperature, its surface emissivity is proportional to the microslug temperature-time derivative, $\left(\frac{dt_s}{d\theta}\right)_{\text{test sample}}$. If one next uses the microslug radiometer to measure the radiation coming from a standard surface with known emissivity at the same temperature level and for the same angle factor, the emissivity of the standard material is also proportional to the microslug temperature-time derivative, $\left(\frac{dt_s}{d\theta}\right)_{\text{standard}}$. Therefore,

$$\frac{\varepsilon_{\text{test sample}}}{\varepsilon_{\text{standard}}} = \frac{\left(\frac{dt_s}{d\theta}\right)_{\text{test sample}}}{\left(\frac{dt_s}{d\theta}\right)_{\text{standard}}} \qquad (4)$$

Thus, Equation (4) can be used more directly to calculate the infrared emissivity.

IV. THERMAL COEFFICIENT OF EXPANSION

The method of measurement which was used is that of ASTM E-228, which utilizes a quartz dilatometer. This instrument, which is shown schematically in Figure 3, accepts samples up to 5 inches long, and utilizes a dial gage readable to 2 x 10^{-5} inches for measurement of sample extension. The relationship between the measured extension for a given temperature change and the coefficient reported is

$$\alpha_T = \frac{\Delta \ell}{\ell \, (T_2 - T_1)} + \alpha_q \tag{5}$$

$\Delta\ell$ is the length change shown on the dial gage

ℓ is the sample length

T_2 and T_1 are the upper and lower temperatures respectively

and α_q is the expansion coefficient for the quartz from which the dilatometer is constructed

The values of α_q are taken from published data.

The resultant value α_T is an average for the temperature range $T_1 < T < T_2$.

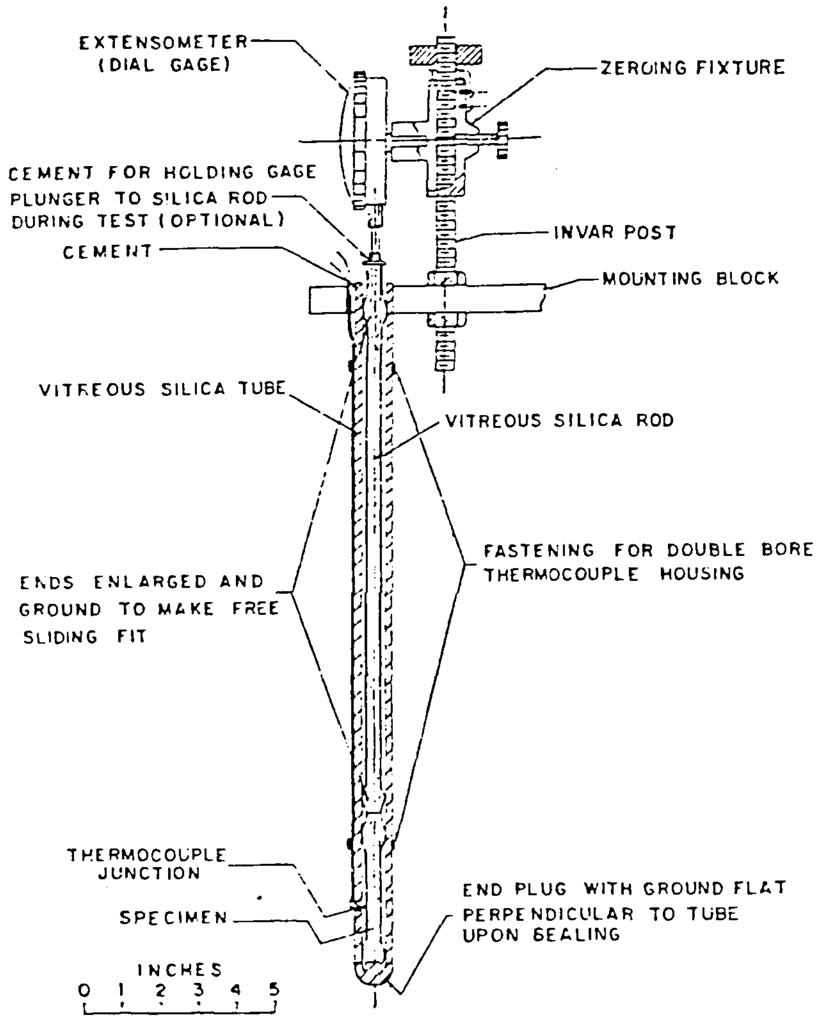


Figure 3. Dilatometer, Tube Type

V. EMISSIVITY MEASUREMENTS FOR CADMIUM TELLURIDE AND GALLIUM ARSENIDE

The new infrared emissivity measurement system was used first to measure the emissivity of cadmium telluride. A temperature level of 700 to 750°F was chosen. The value of 0.90 was determined. This value was in reasonable agreement with an earlier measurement made by Geoscience using a different method and at a lower temperature (namely, the emissivity was found to be 0.80 at a temperature level of 120 to 200°F).

Additional emissivity measurements were made for a gallium arsenide test sample. A value of 0.45 was obtained at a temperature level of 700 to 750°F.

VI. THERMAL COEFFICIENT OF EXPANSION FOR CADMIUM TELLURIDE AND GALLIUM ARSENIDE

A. Gallium Arsenide

The thermal expansion data obtained for gallium arsenide above room temperature are shown in Figure 4. It may be seen that within the scatter of the data the extension of the sample may be represented by two straight lines connected by a curve. The coefficient of linear thermal expansion of gallium arsenide is substantially constant over the temperature range from room temperature to 300°F, and over the range of 380°F to 500°F, and varies from 300 to 380°F.

Recommended values of the coefficient of thermal expansion of gallium arsenide are presented in Table I.

B. Cadmium Telluride

The behavior of cadmium telluride above room temperature is much more ambiguous than that of gallium arsenide. The expanstion data for five consecutive runs for the cadmium telluride are shown in Figure 5.

During the measurements the sample was clearly undergoing some physical change but appeared to be approaching a stable condition as indicated by the run of 4/18/85. A recommended value of coefficient of thermal expansion,

FIGURE 4

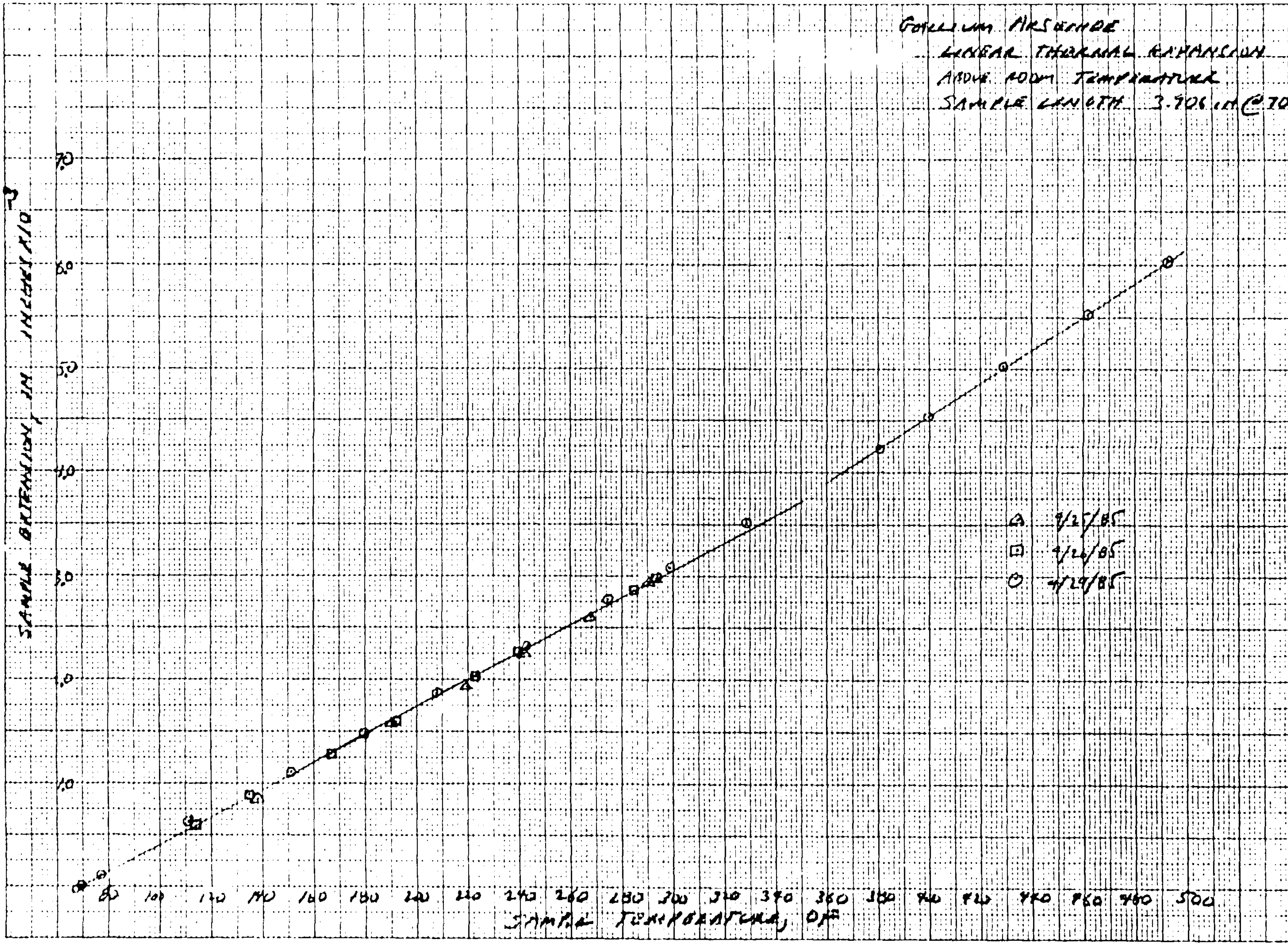

Gallium Arsenide
Linear Thermal Expansion
Above Room Temperature
Sample Length 3.906 in @ 70°F
4/25/85
4/26/85
4/29/85
Sample Extension, in inches x10
7.0
6.0
5.0
4.0
3.0
2.0
1.0
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
Sample Temperature, °F

TABLE I

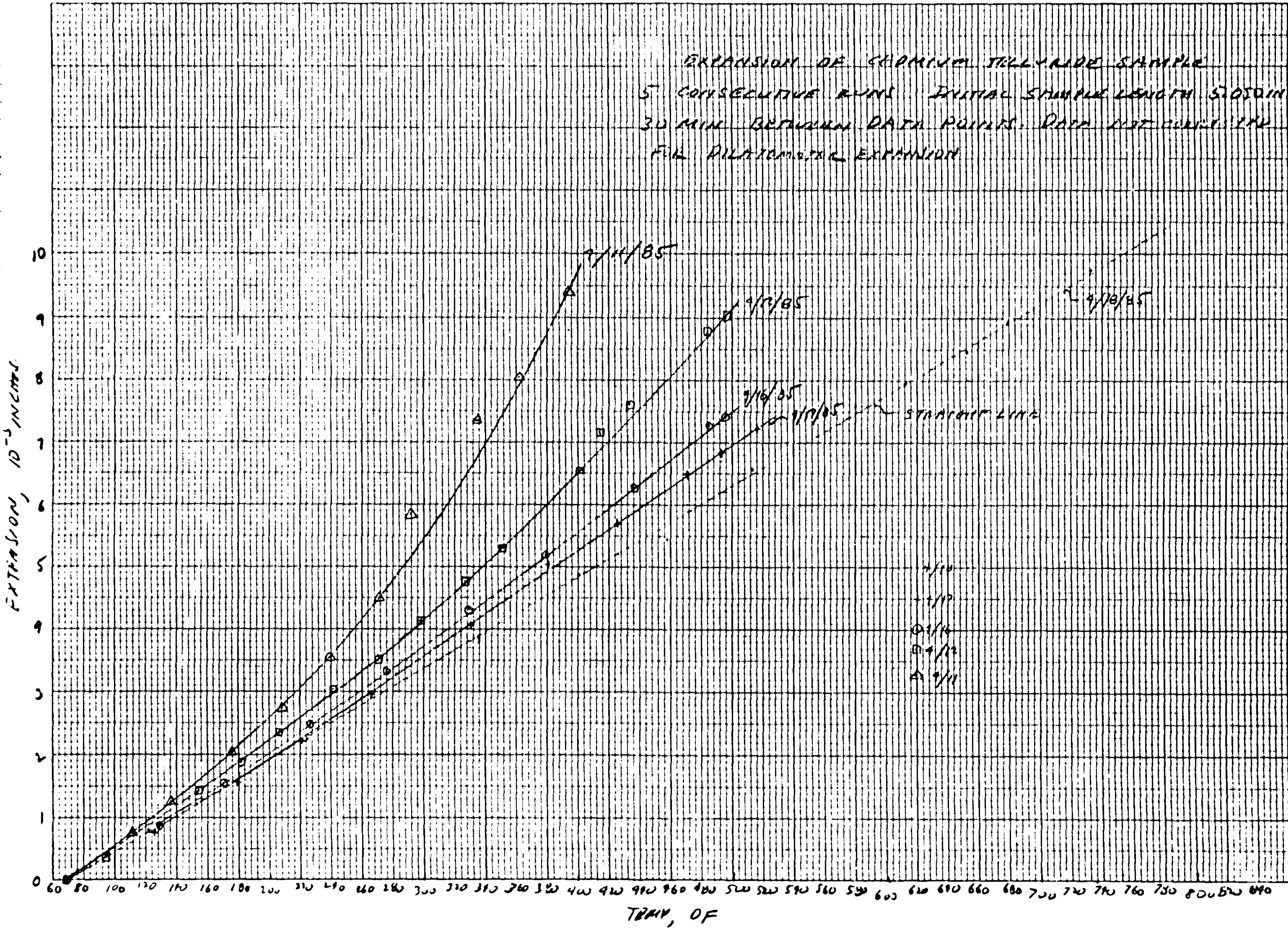
RECOMMENDED VALUES OF THE LINEAR COEFFICIENT OF THERMAL EXPANSION

	$\alpha, \frac{\text{inches}}{\text{inch}^\circ\text{F}}$	Temperature Range
gallium arsenide:		
	$3.7 \times {}^{-6}$	70°F to 300°F
	4.1×10^{-6}	380°F to 500°F
	*	300°F to 380°F
cadmium telluride (thermally aged, see text):		
	3.1×10^{-6}**	-320°F to 70°F
	3.2×10^{-6}	70°F to 780°F

*in this temperature range use a linear interpolation between the two values given.

**this value is tentative.

FIGURE 5


EXPANSION OF CHROMIUM TELLURIDE SAMPLE
5 CONSECUTIVE RUNS INITIAL SAMPLE LENGTH 5.050 IN
30 MIN BETWEEN DATA POINTS
DILATOMETRIC EXPANSION
4/11/85
4/12/85
4/16/85
4/17/85
4/18/85
STRAIGHT LINE
4/18
4/17
4/16
4/12
4/11
EXTENSION, 10^-3 INCHES
TEMP, OF

based on the last run, is given in Table I. Some preliminary low temperature expansion coefficients were also made in a special apparatus and shown in Table I.

VII. DISCUSSION

The plans for continuing work deal with the following tasks:

1. Extend the low temperature thermal expansion coefficient and thermal conductivity data for both cadmium telluride and gallium arsenide.

2. Make additional specific heat measurements of cadmium telluride and gallium arsenide at higher temperatures and

3. Develop conceptual ways of measuring and evaluating the thermal properties for liquid semiconductor materials.

END

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